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MASS SPECTROMETRIC INVESTIGATIONS OF THE ATMOSPHERE BETWEEN 100 AND 227 KILOMETERS ABOVE WALLOPS ISLAND, VIRGINIA

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SUMMARY

The diffusive separation of argon and nitrogen was measured by means of a Bennett radio frequency mass spectrometer carried on an Aerobee-150A rocket, NASA 4.14, launched at 1141 EST, November 15, 1960. The primary purpose of the spectrometer measurements was to obtain temperate latitude diffusive separation data to compare with those measurements obtained in the arctic (Fort Churchill, Canada) during the International Geophysical Year. The results indicated that diffusive separation occurred above about 111 km and that the altitude profile of the A/N_2 ratio is somewhat similar to that obtained during the two night flights in the arctic atmosphere.

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INTRODUCTION

The flight of Aerobee-150A NASA 4.14 marked the 17th time that American scientists have flown the Bennett radio frequency mass spectrometer for the purpose of measuring the composition of the neutral particles of the upper atmosphere.

The first two flights of this instrument were carried out, using Aerobee rockets, by the Applied Physics Laboratory of Johns Hopkins University in 1950 and 1951 (Reference 1). The next 13 flights were made by the Naval Research Laboratory (NRL) from 1952 through 1959. In five of the NRL flights, rocket and instrumentation both performed as intended. However, the first of these five (Reference 2) was contaminated to a great extent by rocket gas; the designs of the experiment and the vehicle were modified accordingly. Four successful firings, during the period 1956-1958, were made in connection with the International Geophysical Year (IGY) program (Reference 3).

All these experiments excepting the last one (in 1958) were designed to scan a mass range of about 8 to 48 atomic mass units (AMU) and were conducted primarily for the purpose of detecting diffusive separation of argon and molecular nitrogen. The last experiment, in 1958, scanned a mass range of 0.7 to 5 AMU and was an exploratory flight for the detection of hydrogen and helium.

Finally, as one of the initial efforts in the NASA program for studying the structure of planetary atmospheres, the Aerobee-150A rockets designated NASA 4.09 and 4.14 were instrumented with Bennett mass spectrometers patterned after those used by NRL in the IGY. Satisfactory data about the neutral composition were not obtained from the flight of NASA 4.09. The data obtained from NASA 4.14 are the principal subject of this report.

Scientists of the USSR have conducted four successful flights in which neutral composition was measured with the radio frequency mass spectrometer (References 4 and 5). Their Model MX-6401 instrument had higher resolving power (1 part in 45) and a longer mass range (1 to 4 and 12 to 56 AMU) than did the American instruments. The Model-6403, an improved, lighter version of the MX-6401, is more sensitive by a factor of 10. The MX-6401 was flown twice in the daytime in July 1959 and also in the late afternoon in November 1961. The MX-6403 was flown at midnight in September 1960.

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In the 1959 and 1960 flights the mass spectrometer was housed in a cannister which was ejected from the vehicle. In the 1961 flight, the mass spectrometer was not separated from the rocket, but was housed in a special container in the payload.

With the exception of the fourth USSR flight (November 1961) which reached an altitude of 430 km all of the above mentioned flights, American and USSR, reached altitudes of less than 250 km.

Several other groups have flown other types of mass spectrometers to study the neutral gases. The first was a magnetic mass spectrometer prepared by R. C. Edwards and J. V. Fay, Jr.,* and flown on a V-2 in 1949 (References 1 and 6). Others include magnetic mass spectrometers (C. Y. Johnson, private communication), time-of-flight spectrometer (R. Narcissi, private communication), and the quadrupole "massenfilter"[†] (E. J. Schaefer, private communication). Rocket and instrumental difficul ties have resulted in less than optimum performance of these experiments.

INSTRUMENTATION

Rockets NASA 4.09 and 4.14 were instrumented at Goddard Space Flight Center to measure, from 100 km to the peak of flight, the pressure, temperature, density, and composition of the neutral particles and positive ions in the earth's atmosphere. The instruments used were Bennett radio frequency mass spectrometers for neutral particles, similar mass spectrometers for atmospheric ions, and Bayard-Alpert ionization pressure gages. The mass spectrometers were patterned after those used by NRL during the IGY (References 3 and 7). Although the technique of using ion gages was the same as that used by NRL during the IGY (Reference 8), the first flight of the Westinghouse No. 4250 version of the Bayard-Alpert gage was aboard NASA 4.14. The locations of the various sensors are shown in Figure 1. This instrumentation was not adequate to give all the aforementioned parameters with constant accuracy over the entire altitude range from 100 km to almost 250 km; but over certain portions of this range, it could provide very good data.

The NASA 4.09 flight was made at 1047 EST on 29 April, 1960, at Wallops Island, Virginia (latitude 37° 50' 06" N, longitude 75 29' 11" W) to an altitude of 248 km. Only the ion mass spectrometer performed properly. The NASA 4.14 flight was made at 1141 EST, 15 November 1960, to 227.3 km, also from Wallops Island. Preliminary inspection of the telemetry records indicated all instruments functioned satisfactorily. A preliminary report of the ion mass spectrometer data has already been published (Reference 9). Analysis of the pressure gage data is not yet complete.

The mass spectrometer for measuring the neutral particle composition of the atmosphere differed from those used during the IGY (Reference 3), in that a 7-5 cycle three-stage analyzer was used, with a resolution of about 1 part in 25. This configuration was selected instead of the four-stage IGY version to obtain greater sensitivity as well as linear operation at higher pressures. The electronic units were substantially the same as used during the IGY, and included: an emission regulator for the

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*This work is described in the Consolidated Final Report on Subcontract No. 1 under Government Contract No. W 33-038 ac-14050, "Mass Spectrometer" by J. Robert Downing, Cook Research Laboratories, Chicago, Illinois, January 13, 1950. The Government contract was to the University of Michigan, College of Engineering, Department of Engineering Research, Ann Arbor, Michigan.

†Note added in proof: First successful firing, May 18, 1962, preliminary data: Schaefer, Edward J., "The Dissociation of Oxygen Measured by a Rocket-Borne Mass Spectrometer" J. Geophys. Res. 68(4)1175-6, Feb. 15, 1963.
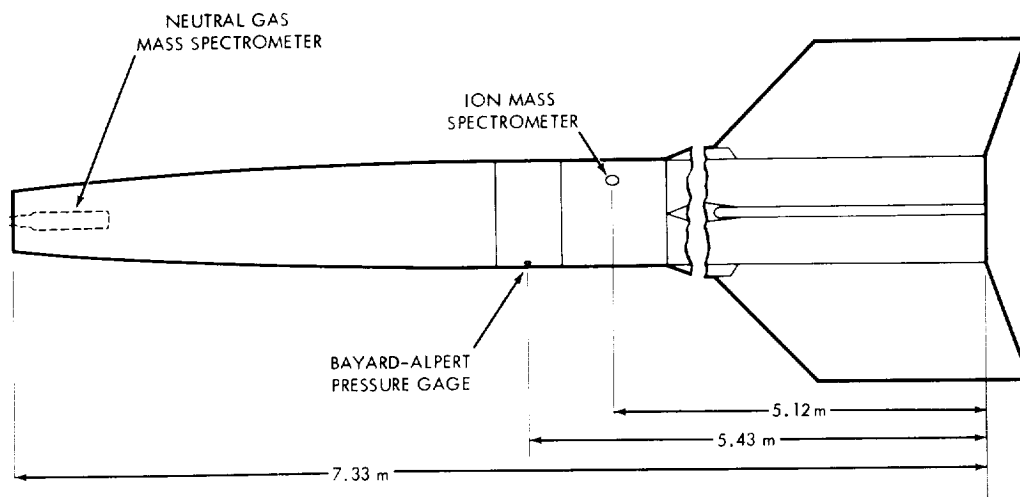
Figure 1—The locations of the three principal sensors on NASA 4.14. These positions were chosen to obtain maximum isolation of the experiments from each other. The sun and earth sensors for aspect determination are on the hidden side.

ilament; an RF oscillator, from which the bias and stopping potentials for the analyzer were derived; . motor driven potentiometer for the voltage sweep; a 100 percent negative feedback dc amplifier to neasure the ion current; and suitable regulated power supplies. The mass range of 8 to 48 AMU was swept once each 1.4 seconds. The ion source used 45-volt electrons at a nominal current of 10 ma.)ther operating potentials were: RF potential, 7.7 vrms at 4.2 Mc; bias, 15.4 v; and stopping, 44.8 v.

Laboratory calibrations of the mass spectrometer included the admission of dry air through a molecular-flow type variable leak. Four calibration runs on different days with various settings of operating potentials were plotted as Ar^+/N_2^+ versus pressure over the pressure range from 10^{-6} to almost 10^{-3} mm Hg: the points had a scatter of $\pm$ 15 percent about the curve drawn in Figure 2. Also plotted in Figure 2 is the ratio of the argon and molecular nitrogen currents as a function of the total pressure in the mass spectrometer. This ratio was found to be independent of stopping potential and of electron emission over the range of these potentials expected in flight. The ratio was independent of pressure below about 5×10^{-5} mm Hg, but increased slowly at higher pressures as a consequence of the relatively greater probability for collisions of N_2^+ with neutral particles. The total ion current, which is the sum of the individual ion currents at the various mass numbers, was used as a monitor of the total pressure within the tube. The pressure calibration was obtained by means of a VG-1A ionization pressure gage located adjacent to the mass spectrometer on the vacuum system. Total spectrometer ion current was linear with respect to pressure up to 4×10^{-5} mm Hg and had its maximum value at 4.3×10^{-4} mm Hg.

After calibration of the spectrometer was completed the tube was baked in an evacuated condition and sealed. A getter, confined to the removeable tip, was flashed. The tube was then sealed with O-ring gaskets to a bulkhead at the forward end of the rocket, about 19 inches back from the nose tip. After the top 19 inches of the rocket and the tip of the spectrometer were removed during flight at an altitude of 100 km, the opening of the spectrometer extended slightly above the bulkhead. The opening did not "see" any part of the surface of the vehicle.

DATA

The basic data concerning the flight of the rocket are given in Table 1. The angle of attack is the angle between the total velocity vector of the rocket and the longitudinal axis of the spectrometer. Up to 172.4 seconds the position and velocity data were obtained from tracking radars, and the subsequent positions and velocities were computed for free-fall conditions. The peak altitude is known with an error of ± 0.5 km. The direction of the rocket axis was determined from two rocket-mounted magnetometers and a sun-earth sensor with an accuracy of ± 3 degrees. After thrust termination, the rocket's horizontal velocity was constant at 0.145 km/sec in a direction 152 degrees east of north, until the vehicle re-entered at about 85 km. The vehicle spun about its longitudinal axis at a rate of 2.69 rpm and precessed in a cone of 4.6 degrees half angle; the cone axis was tipped 10.8 degrees from zenith in a direction 15.5 degrees west of north.
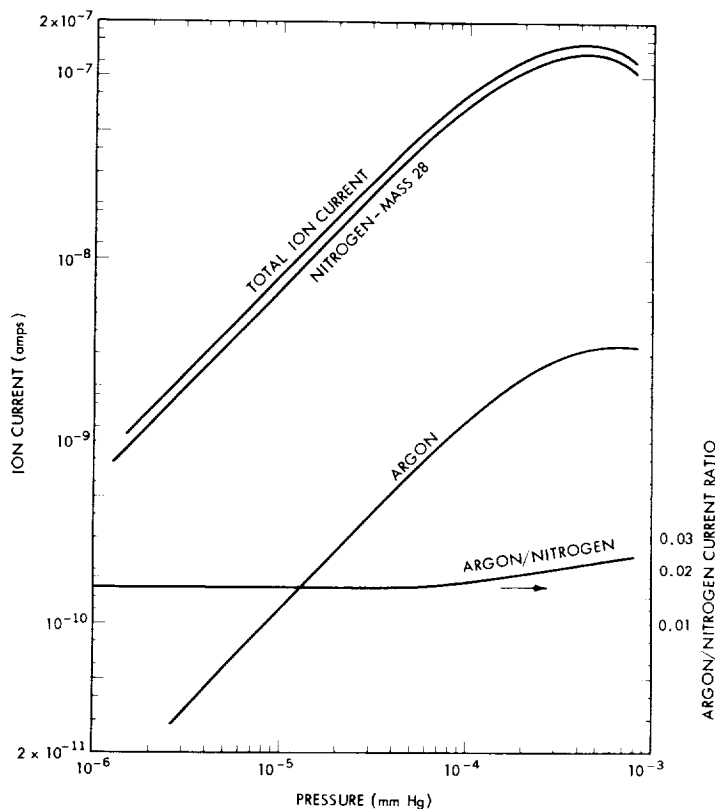
Figure 2—Calibration data for the mass spectrometer flown in NASA 4.14. The curves have been adjusted so that the sensitivity corresponds to the operating conditions used in flight.

The basic data obtained from the spectrometer are given in Figures 3, 4, 5, and 6. The output from the electrometer was telemetered on three channels each of which covered about one order of magnitude.

Figure 3 shows the spectrometer collector current due to nitrogen at 28 and 14 AMU, argon at 40 AMU, and the total ion current for these and the remaining species sensed by the spectrometer. The total does not include the current due to atmospheric ions. In Figure 3 the actual data points for molecular nitrogen and for argon are shown to indicate the scatter present in the various current and altitude ranges; the scatter is similar for the other constituents.

In Figure 4 are plotted the ion currents for oxygen at 32 and 16 AMU, nitric oxide at 30 AMU, and some very small unidentified peaks at 26 and 34 AMU. In Figure 5 are plotted carbon dioxide appearing as currents at 44 and 12 AMU, and water vapor at 18 and 17 AMU.

The ambient atmospheric ions also enter the analyzer. Because the rocket acquires a negative potential of a few volts with respect to the ionosphere, the ions and their harmonics appear and both are displaced on the mass scale. Thus, the atomic oxygen ion appears at 15.3 AMU, the molecular

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Table 1

Summary of Trajectory and Aspect Data for NASA 4.14

Altitude (km Above Sea Level)	Rocket Total Velocity (km/sec)	Ascent		Descent	
		Time (sec)	Angle of Attack* (deg)	Time (sec)	Angle of Attack* (deg)
100	1.545	87.5	6.3	420.4	160.8
110	1.484	94.0	9.6	414.0	159.9
120	1.418	101.0	11.7	407.0	160.9
130	1.350	108.2	12.1	399.7	163.8
140	1.280	115.8	10.7	392.0	166.9
150	1.202	124.4	7.0	384.2	168.0
160	1.123	132.8	3.1	375.2	164.9
170	1.036	142.0	5.3	365.7	159.9
180	0.942	152.5	10.3	355.7	157.2
190	0.838	163.5	12.3	344.2	159.0
200	0.722	176.8	8.8	331.3	163.1
210	0.580	192.5	6.5	315.6	158.2
220	0.393	214.1	20.5	294.1	145.3
225	0.251	231.6	26.4	276.4	139.3
227.3	0.145	253.75	82.0	253.75	82.0

*The angle of attack is the angle between the total velocity vector of the rocket and the longitudinal axis of the spectrometer.

oxygen ion at 31.2 AMU, and the nitric oxide ion at 29.4 AMU. The lower harmonics appear in the spectra at the following positions: 32^+ at 23.2 AMU, 30^+ at 21.7 AMU, 28^+ at 20.2 AMU, and 16^+ at 11.4 AMU. The fundamental peak for ambient 28^+ is obscured by the very large peak due to neutral nitrogen. The variations of these peaks with time and altitude are shown in Figure 6.

ANALYSIS OF DATA

Certain constituents of the atmosphere—nitrogen, argon, and the other noble gases—exist in fixed ratios at the earth's surface. Winds and turbulence preserve these ratios up to a high altitude. With diminishing density the speed of molecular diffusion increases, and the density profile of each permanent gas above some altitude is controlled principally by temperature and gravity. This results in a decreasing ratio of the concentration of heavy gases to that of lighter gases above the altitude at which mixing is no longer effective.

The effect of diffusive separation is noted in the mass spectra that were obtained by considering the data for argon and molecular nitrogen. The following relation between the pressure within the

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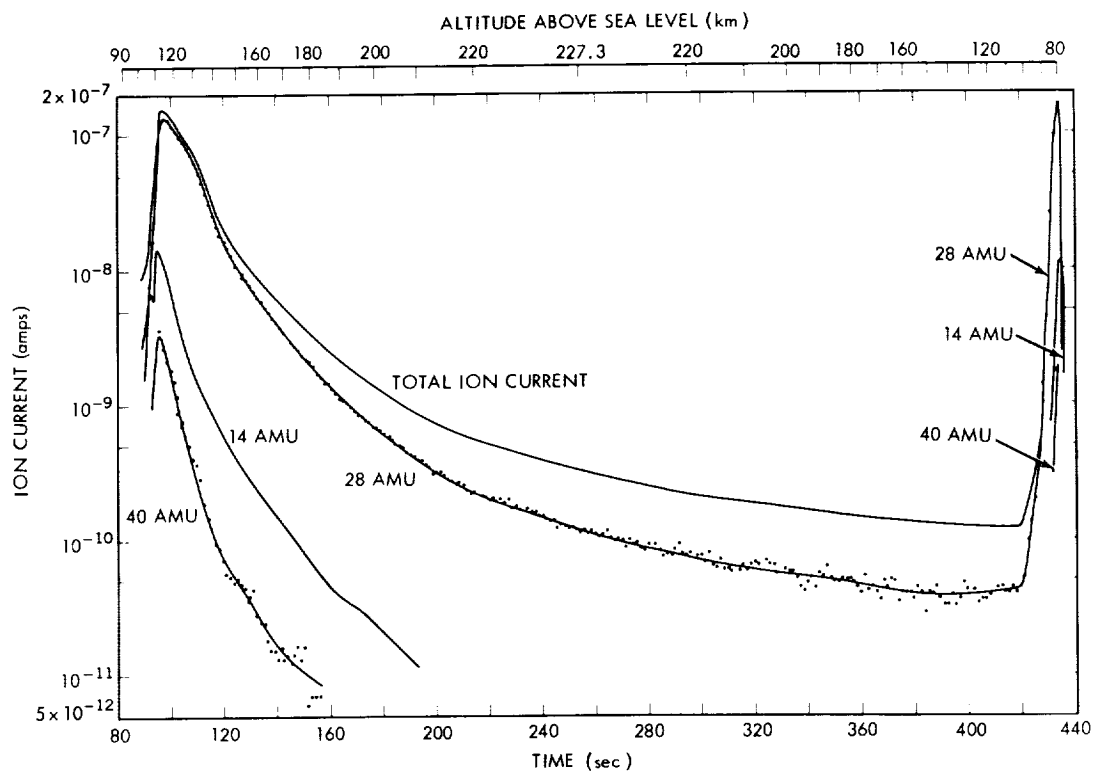
ALTITUDE ABOVE SEA LEVEL (km)

Figure 3—The major atmospheric gases: molecular nitrogen at 28 AMU and argon at 40 AMU; and the total ion current which is a measure of the total pressure within the mass spectrometer.
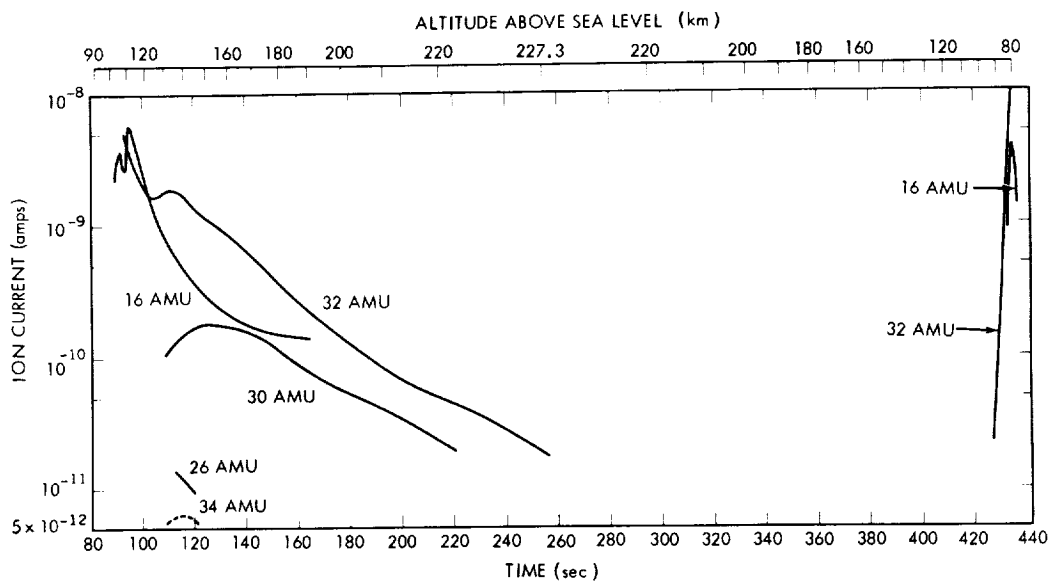

Figure 4—Molecular and atomic oxygen, unidentified peaks of 26 and 34 AMU, and the nitric oxide ion produced within the mass spectrometer by an ion-molecule reaction.
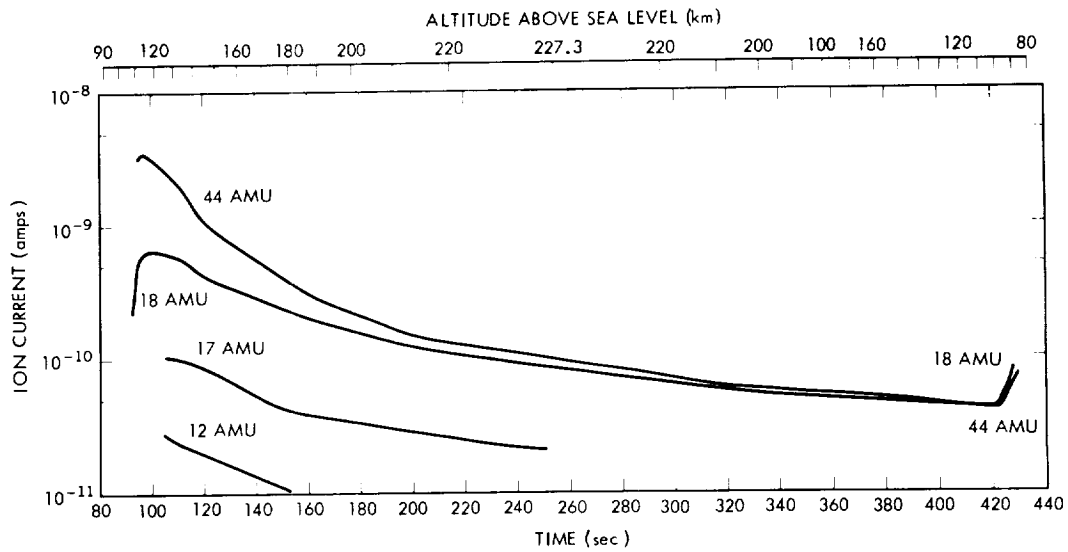
ALTITUDE ABOVE SEA LEVEL (km)

Figure 5—Rocket gas: carbon dioxide and water vapor.
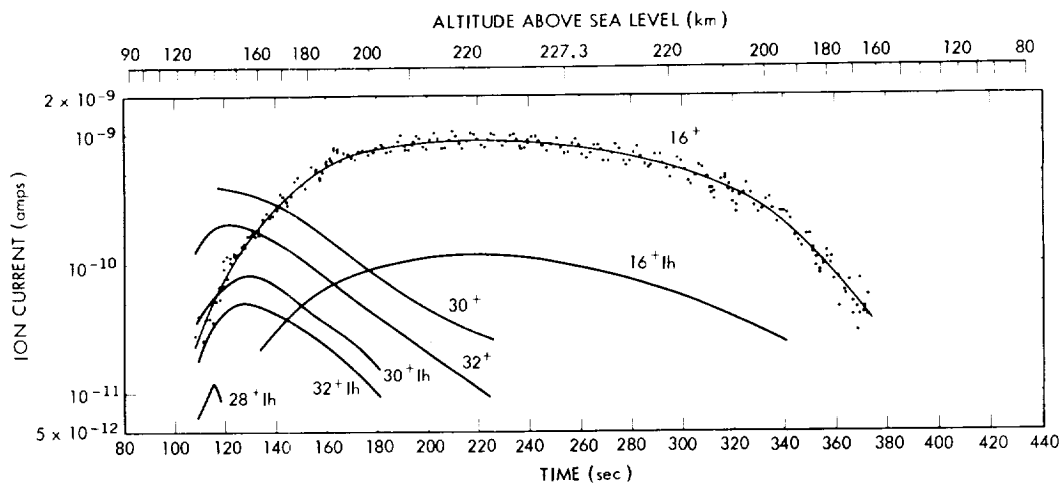

ALTITUDE ABOVE SEA LEVEL (km)

Figure 6—Ambient ions and their harmonics. The fundamental peak of the 28^+ ion was hidden by the ions formed from the neutral nitrogen

spectrometer P_g and the ambient density of the constituent ρ_a is used (Reference 10):

$$\rho_a = \frac{P_g}{F(s) R \left(T_a T_g\right)^{1/2}},$$

where

R = the gas constant k/m,

k = Boltzmann's constant;

m = mass of each gas particle;

T_a = ambient temperature of the atmosphere;

T_g = temperature of the gas within the spectrometer; and

$F(s)$ = $s\sqrt{\pi}\left[1 + \mathrm{erf}(s)\right] + e^{-s^2}$, in which $s = V/V_a$, V is the velocity vector of the vehicle along the spectrometer tube axis, and V_a is the most probable speed of the atmospheric constituent considered.

For $s > 1$, the velocity function $F(s)$ is approximately equal to $2s\sqrt{\pi}$. With this and using the expression for the most probable velocity, $V_a = \left(2RT_a\right)^{1/2}$, the ambient density is given by

$$\rho_a = \frac{P_g}{VV_g\sqrt{\pi}} = \frac{P_g}{V\left(2\pi k\,\dfrac{T_g}{m}\right)^{1/2}} \quad ,$$

where V_g is the most probable velocity of the particles inside the spectrometer tube.

The foregoing discussion is valid for a chamber open to the atmosphere through an orifice. When there is a tube between the chamber and the atmosphere, as is true in this experiment, P_g must be multiplied by a function C which depends on the angle of attack, the geometry of the opening, the total velocity of the vehicle, and the accommodation coefficient of the impinging particles on the surface of the tube. For the geometry used in this experiment, C has a lower limit of 1/2 when the angle of attack is 0 and a value of 1 when the angle of attack is 90 degrees. The value of C may be greater than 1 for intermediate angles of attack. It is assumed that C is the same for argon and nitrogen and will cancel when the ratio of their densities is taken; thus

$$\left(\frac{\rho_{Ar}}{\rho_{N_2}}\right)_{flight} = \frac{P_{Ar}}{P_{N_2}}\left(\frac{28}{40}\right)^{1/2} \quad ,$$

where ρ is the density of the atmosphere, P is the pressure within the spectrometer, and the subscripts Ar and N_2 refer to argon and molecular nitrogen, respectively.

Of principal interest is the comparison of the values of this ratio ρ_{Ar}/ρ_{N_2} in the upper atmosphere to that for ground level air. In terms of ion current, I_{Ar} at 40 AMU and I_{N_2} at 28 AMU, the ratio of the pressures in the mass spectrometer during calibration is given by

$$\frac{P_{Ar}}{P_{N_2}} = \left(\frac{\rho_{Ar}}{\rho_{N_2}}\right)_{ground} = A\left(\frac{I_{Ar}}{I_{N_2}}\right)_{ground} \quad ,$$

where the subscript ground indicates the calibration with ground level air, and where A is the ratio of the sensitivity of the mass spectrometer for argon to its sensitivity for nitrogen. The variation of A with the total pressure within the mass spectrometer can be noted in Figure 2 where the argon/nitrogen

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curve represents $P_{Ar}/P_{N_2}A$. For this type of mass spectrometer A has been found to be independent of the relative abundances of nitrogen and argon when $P_{Ar}/P_{N_2} < 0.02$. Thus, A will cancel in the following, which defines the separation ratio r:

$$r = \frac{\left(\dfrac{\rho_{Ar}}{\rho_{N_2}}\right)_{flight}}{\left(\dfrac{\rho_{Ar}}{\rho_{N_2}}\right)_{ground}} = \frac{\left(\dfrac{28}{40}\right)^{1/2}\left(\dfrac{I_{Ar}}{I_{N_2}}\right)_{flight}}{\left(\dfrac{I_{Ar}}{I_{N_2}}\right)_{ground}},$$

where the current ratios for flight data and ground data are taken at the same total pressure in the mass spectrometer. The total pressure in the mass spectrometer during flight was measured by the total ion current observed and the calibration curve of Figure 2.

The data used to calculate the separation ratio are given in Figures 2 and 3. During the period of interest, from 96 to 155 seconds, the emission current from the filament in the ion source ranged from 10.0 to 10.8 ma; however, all the plotted data have been normalized to a current of 10.0 ma. During the first few seconds of operation of the spectrometer tube in flight, that is, from 89 to 95 seconds, a glow discharge apparently occurred in the ion source, with the result that the values of ion currents were not proportional to emission current and resolution of the spectrometer was impaired during that interval of time. The data from these spectra were not used in the computations.

The result, the separation ratio, is shown in Figure 7. The points are derived from the values of the smooth curves in Figure 3, read at the altitudes in question. The error in this curve (Figure 7) is judged to be no more than ± 20 percent from systematic and reading errors. The reading errors rise rapidly with altitude above 150 km; the extension of the separation ratio is shown in Figure 9 only to indicate the trend.

DISCUSSION

Ambient Ions

Atmospheric ions also enter the spectrometer and appear in the spectra, displaced about one half a mass unit from ions of the same mass produced in the ion source. The displacement is due to the initial energy the ions acquire from the negative potential that the vehicle has with respect to the ionosphere. The data for
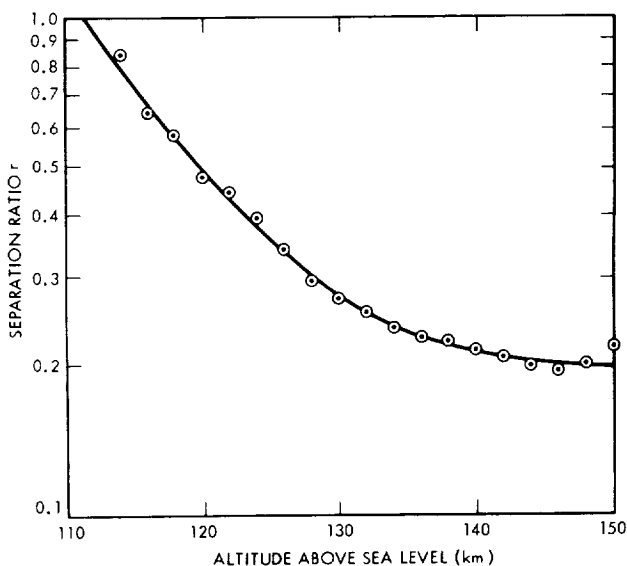

Figure 7—The separation ratio r is the value of the ratio of the argon and molecular nitrogen densities measured in flight compared to the value for the same ratio measured for ground level air. This curve is for NASA 4.14, November 15, 1960, 1141 EST.

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these ions are shown in Figure 6. The experimental data for atomic oxygen ions are given to show the cyclic variation of 15 to 20 percent with time. This correlates well with the phase of the roll angle. The reason for this pattern is not clear, for the experiment was intended to be symmetrical about the roll axis, and no similar variation was noted for the neutral particles. One possible explanation is that a trace of foreign material on one side of the interior of the spectrometer tube entrance yielded photoelectrons copiously, reducing the number of ions which successfully reached the analyzer. Such a phenomenon was noted in the data from the ion spectrometer flown in Viking 10 (May 7, 1954), in which the ion current was correlated with the angle of the sun (Reference 11). Another possible explanation assumes a nonsymmetrical distribution of magnetically permeable material near the entrance such that the resultant field, as modified by the material's interaction with the earth's magnetic field, depended on the phase of the roll angle. Hence, the mean free path and density of the electrons in the entrance tube may have changed in response to the varying magnetic field altering the probability of ambient ions reaching the analyzer.

The relative altitude distribution of the ambient ions measured by the neutral gas spectrometer is shown in Figure 8. These data support the measurement of ion composition by the ion spectrometer on this vehicle as reported earlier by Taylor and Brinton (Reference 9), and as indicated in Figure 8.

Other Gases

Little useful information about the upper atmosphere was obtained from the remaining ion current peaks. Mass number 14 (N^+) appears (Figure 3) as the result of dissociative ionization of molecular nitrogen within the spectrometer's ion source as well as from ionization of atomic nitrogen. All the mass 14 ion current in these spectra is attributed to molecular nitrogen. Any atmospheric atomic nitrogen either disappeared on the surfaces of the spectrometer, or its abundance is less than 4 percent of that of molecular nitrogen.

No completely plausible explanation has been found for the shape of the altitude profiles of mass numbers 16 (O^+) and 32 (O_2^+) in Figure 4. It may be that immediately after the spectrometer was opened to the atmosphere both atomic and molecular oxygen were adsorbed on the surfaces of the spectrometer. After 120 seconds, the principal source of
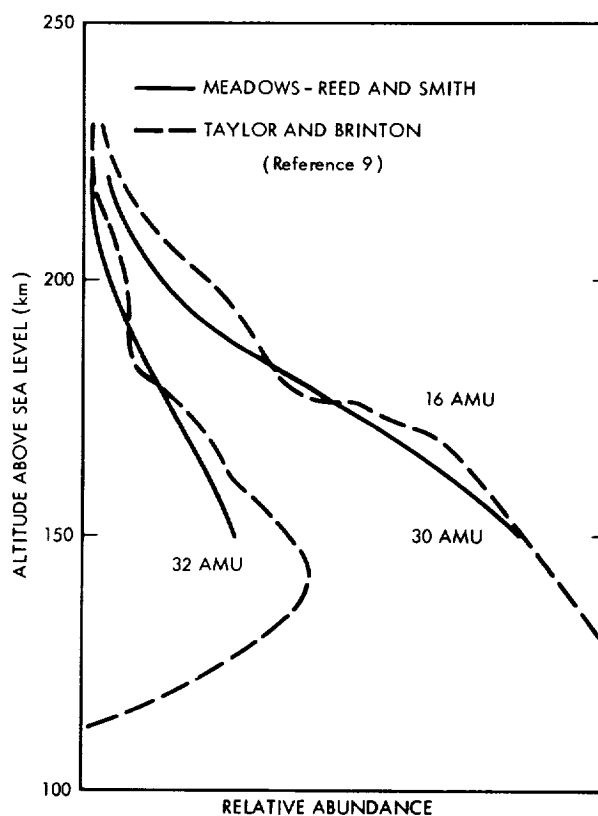

Figure 8—Ion composition measured by NASA 4.14. The relative width of the horizontal space allotted to each species indicates its relative abundance. Not included is the trace of the 28 AMU ion noted between 132 and 142 km.

molecular oxygen within the spectrometer may be the gas released from these surfaces, the supply to the surface being constantly replenished by the oxygen atoms and molecules from the atmosphere. It does not seem possible to deduce from these data the relative abundance of atomic and molecular oxygen either with respect to each other or to the total atmosphere. The nitric oxide peak (30 AMU) comes from charge exchange phenomena within the ion source of the mass spectrometer (Reference 12).

Carbon dioxide and water vapor, represented by 44 $\left(CO_2^+\right)$ and 18 $\left(H_2O^+\right)$ in Figure 5, have been consistently observed in the spectra from the various rocket flights of the mass spectrometer, and are presumed to come from the vehicle. There is also in the spectra the secondary peak due to water vapor $\left(OH^+ \text{ at } 17 \text{ AMU}\right)$ with an amplitude of about 0.3 that of the 18 AMU ion current peak, and a small peak at mass 12, probably due to C^+ from the carbon dioxide. Other small peaks occurred at mass numbers 34 and 26 (Figure 4). Their chemical composition and origin have not yet been explained.

Diffusive Separation

A summary of data concerning the distribution of argon and nitrogen is shown in Figure 9. All the data below 110 km were obtained from the laboratory analysis of gas samples collected by rocket borne sample bottles flown at temperate latitudes. The first American samples were obtained from
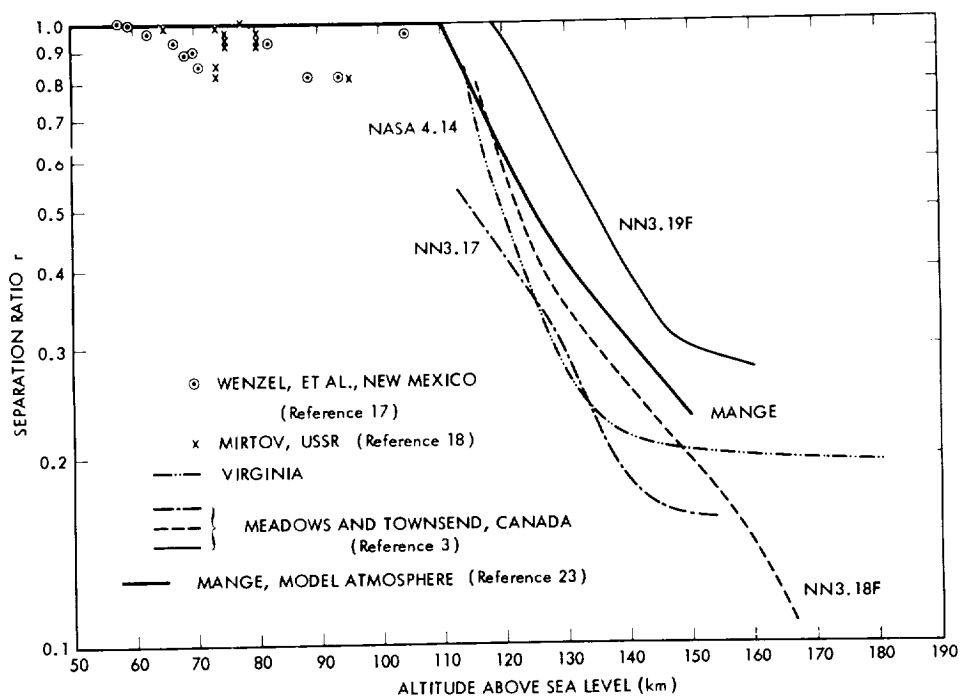

Figure 9—Summary of data concerning the relative abundance of argon and nitrogen at various altitudes.

bottles flown on Aerobee rockets by Jones et al., of the Department of Aeronautical Engineering at the University of Michigan. The data shown in Figure 9 are from samples obtained from four Aerobee rockets and a V-2 rocket flown between 1950 and 1956 at White Sands Proving Ground in New Mexico. The samples, collected in steel bottles, were divided and analyzed by the group at the University of Michigan and by Professor Paneth of Mainz by separation of the various constituents. A comprehensive series of articles describing these experiments appears in the literature (References 13-16); a summary article of the program was written by Wenzel, Loh, et al., (Reference 17).

Scientists of the USSR collected a number of air samples on rocket flights from 1951 through 1956. Their techniques of collection and analysis were quite different from those employed in the United States. The containers were of glass and the analyses were carried out by studying the emission line of the gas when subjected to a high frequency discharge. Their results, as presented in the summary article by Mirtov (Reference 18), are also plotted in Figure 9.

Of the flights of the radio frequency mass spectrometer prior to the IGY program only one, Aerobe NRL-13, yielded acceptable spectra. There was no evidence of diffusive separation of argon and molecular nitrogen in these data, at a maximum altitude of 137 km (Reference 2). However, the nitrogen pressure in the spectrometer was about a factor of 10 greater than that which would be predicted from the various model atmospheres. It is now believed by the authors that the data obtained constituted a better measure of the composition of the air escaping from the interior of the rocket's nose cone than of the ambient atmosphere.

The information concerning the distribution of argon and nitrogen obtained with radio frequency mass spectrometers flown by the USSR scientists has been summarized by Pokhunkov (Reference 19). He found that both in the day and night atmospheres there is gravitational separation of argon and nitrogen. At night (midnight, September 9, 1960) this separation begins in the 105 to 110 km altitude region. The definition of this level in the day atmosphere was difficult: in the first two flights (morning, July 14 and 22, 1959) there were a limited number of data points near 100 km; in the last flight (late afternoon, November 15, 1961) the experiment was placed in operation and began to record spectra at 130 km. However, the data observed were in agreement for all three experiments and show appreciable separation of argon and nitrogen.

The data above 110 km shown in Figure 9 include the results from the mass spectrometers mounted on the pre-IGY rocket NN3.17 and the two IGY rockets NN3.18F and NN3.19F flown at Fort Churchill, Canada.

The pre-IGY flight occurred at 2321 CST on November 20, 1956. Although auroral activity was observed during the evening and ground magnetograms indicated a disturbed magnetic condition, an overcast sky prevented visual auroral observations at the time of firing. Though there may have been some auroral activity then, there was no evidence of a major display in progress. Care should be taken in extrapolating the curve of NN3.17 toward lower altitudes: Since the temperatures in this region are low (200° to 250°K), it is expected that the separation ratio would attain a value of 1 somewhat above 100 km. The second firing, NN3.18F, was at 2002 CST on February 21, 1958. An auroral display observed visually was too weak and diffuse for ground camera recording; it is not known whether the vehicle entered the aurora.

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It is believed that these two flights (NN3.17 and NN3.18F) can be considered typical of the arctic nighttime atmosphere.

The third flight, NN3.19F, was carried out at 1207 CST on March 22, 1958, during a polar blackout. An additional influx of energy, in the form of 10 to 100 Mev particles or x rays or both, is associated with polar blackout. The absorption of this energy results in heating and turbulence, possibly changing both the extent of mixing and the temperature profile of the atmosphere.

The last flight, NASA 4.14, at 1141 EST, was made at a temperate latitude; ionograms indicated that the ionosphere was becoming quiet after a period of moderate disturbance. However, the Fredericksburg Magnetic Observatory at Corbin, Virginia, recorded a moderately severe magnetic storm from 0804 to 1221 EST (Reference 20) and the sunspot number was high, 133 (Reference 21).

Both Nicolet (Reference 22) and Mange (Reference 23) have considered the distribution of argon as modified by the process of diffusion. Mange computed the altitude dependence of various atmospheric constituent concentrations in diffusive equilibrium above an arbitrary altitude of 110 km, with a temperature of 318°K at 120 km, and a temperature increase with height of 6 deg/km. The curve labeled Mange in Figure 9, shown for comparison with the experimental data, is obtained from the computation by Mange presented in Figure 1 of his paper.

CONCLUSION

In conclusion, it may be said that the level at which diffusive separation of argon and molecular nitrogen becomes effective has been measured and found to vary from about 100 to 119 km, with typical values between 110 and 112 km.

ACKNOWLEDGMENTS

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